PULSATILE FLOW IN A HELICALLY COILED TUBE-IN-TUBE HEAT EXCHANGER

A REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master's of Technology in Thermal Engineering

by

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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CERTIFICATE

This is to certify that the thesis entitled **Pulsatile flow in a helically coiled tube-in-tube heat exchanger** , submitted by **Debiprasad Sahoo** to National Institute of Technology, Rourkela, is an authentic record of bona fide research work carried under my supervision and I consider it worthy of consideration for the award of the degree of Master's of Technology of the Institute.

. . . .

Date:

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I am also greatly indebted to my parents who have supported me both morally and financially throughout my career and without whose support completing my M.Tech career would not have been possible.

Date:

Place: Debiprasad Sahoo

DECLARATION

I certify that

1. The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

2. The work has not been submitted to any other Institute for any degree or diploma.

3. I have followed the guidelines provided by the Institute in writing the thesis.

4. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

Debiprasad Sahoo

Abstract

Heat exchangers have achieved extensive applications in modern days in every field. They have got wide applications in automobile industries, food processing operations, aerospace applications. Among different types of heat exchangers, helical tube heat exchangers have gained much popularity due to their compactness and effectiveness. Helical heat exchngers provide greater surface area for heat exchange for same floor space. In this paper pulsating flow(both parallel and counter flow) is studied in a model of a helical tube-in-tube heat exchanger using ANSYS 15.0. The results are compared with constant flow(both parallel and counter flow) in the same model of the helical tube-in-tube heat exchanger. Then further analysis is done by studying pulsating flow (both parallel and counter flow) in the same model of helical tube-in-tube heat exchanger but by fixing a thin wire on the surface of the inner helical tube of the heat exchanger model. All analysis is done using ANSYS 15.0 for flow time of 60 seconds in each case. The temperature drops for the hotter fluid and temperature rise for the colder fluid is studied for each case and then comparision is done to establish the best configuration of the above. It is observed that the temperature drop for the hot fluid and temperature rise for cold fluid is: Constant velocity flow < Pulsating flow < Pulsating flow with wire.

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Chapter 1

INTRODUCTION

1.1 Introduction

Heat exchanger is an equipment which is used to exchange heat between hot fluid and cold fluid flowing through different pipes. Heat exchangers have got extensive applications in industrial as well as day to day home appliances. Refrigerators, air conditioners, automobile radiators, industrial boilers, etc.. are some of the large number of fields which implement the use of heat exchangers. Heat exchangers are becoming a part of our day to day life. They have also got important applications in thermal power plants and food industry.

1.2 Classification of heat exchangers

1.2.1 Based on heat transfer method:

1. Direct contact heat exchanger-The hot and cold fluids flowing in different channels are mixed directly to exchange heat between themselves.

2. Direct Transfer heat exchanger-The hot and cold fluids exchange heat between themselves through a thin wall.

3. Regenerative heat exchanger-both fluids are flowing through the same matrix and the matrix is rotating to alternate the inlets and outlets of the hot and cold fluids.

1.2.2 Based on design

1. Tube-in-tube heat exchanger-One fluid flows through the inner tube and the other fluid flows through the annular outer tube. The heat exchange takes place through the inner

tube walls.

2. Shell and tube heat exchanger-It consists of a shell and number of parallel tubes. One fluid flows through the shell and the other fluid flows through the tubes. The heat exhange occurs at the shell-tube interface.

3. Finned tube heat exchanger-Addition of fins on the heat exchange surface, increases the surface area available for heat exchange. These are generally used if the two fluids are of different phases.

1.2.3 Based on flow type

1. Parallel flow- Both fluids flow in the same direction

2. Counter flow-Both fluids flow in opposite directions.

3. Cross flow-Both fluids flow at right angles to each other.

1.3 Helically coiled heat exchangers

Helically coiled heat exchangers are growing in applications. They are advantageous over the straight tubed heat exchangers in a number of ways:

1. Due to secondary turbulence created the heat exchange is more in case of helically coiled heat exhanger than straight tubed.

2. It can be accomodated in lesser floor space while giving same heat echange as compared to straight ones.

3. In the same amount of space available, it provides larger heat transfer surface area.

1.4 Applications of helically coiled heat exchangers

1. Thermal Power generation plants

2. Nuclear power plants

3. Food processing plants

4. Chemical industries

5. Automobile radiators
6. Cryogenic plants
7. Refrigeration
8. Air Conditioning

1.5 Aim of the project

The primary aim of the project was to obtain a standard model of a helical tube-in-tube heat exchanger using ANSYS 15.0. Then constant velocity flow and pulsating velocity flow was to be achieved in the same standard model. for the same flow time for both the types of velocities, parallel fow and counter flow cases were studied. The temperature drop for hotter fluid and temperature rise for colder fluids were to be measured using FLUENT and compared for the constant velocity flow cases and pulsating velocity flow cases.

Later the work was extended to adding a thin wire over the inner tube outer surface. Then simulation was done for pulsating flow in the heat exchanger with thin wire for both parallel flow and counter flow cases. Then again comparision was done to see the temperature drop of hot fluid and temperature rise for cold fluid.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Development in computational methods have enabled researchers to easily simulate real life problems. These are leading to faster development in technology. A number of CFD tools like ANSYS have emerged which help a lot in simulating real life problems. These help in analysing existing models to modify them for better results or in developing new models.

Earlier work has been done based on performance of helical tube-in-tube heat exchangers. Number of research work has been carried out to improve the performance of the heat exchanger by increasing the heat transfer rate. But very limited work has been carried out related to pulsating velocity flow in a helically tube-in-tube heat exchanger . Also not much research has been done related to study of flow in a helical tube-in-tube heat exchanger with a thin wire attached over the outer surface of the inner helical tube of the helical tube-in-tube heat exchanger.

Some journals and papers that really helped in carrying out the research topic are mentioned in the next section.

2.2 Earlier research works

- Research was done for helically coiled heat exchanger with wet surface conditions by Wongwises et al in 2006[16]. They noticed that outlet temperature and other parameters of air and water passing through a helically coiled heat exchanger is dependent on the inlet temperature and other parameters. With rise in mass flow rate of air and water the outlet temperature decreases.

- Kumar et al in 2006[11] worked on studying the heat transfer characteristics of helically coiled tube-in-tube heat exchanger at pilot plant scale. They calculated the overall heat transfer coefficient(U) using a counter-flow type heat exchanger. They concluded that U rises with increase in inner tube Dean Number.

- Jayakumar et al(2008)[8] carried out work on fluid to fluid heat transfer in a helically coiled tube-in-tube heat exchanger. They worked on different boundary conditions like constant wall temperature, constant heat flux and constant convective heat transfer coefficient conditions. They formulated the inner heat transfer coefficient for helically coiled heat exchanger

- Kharat et al(2009)[10] worked on developin a correlation for convective heat transfer coefficient for a helically coiled tube-in-tube heat exchanger. They tried to improve the convective heat transfer coefficient by varying different operating variables like gap between inner and outer tubes, coil diametre and wire diametre. With rise in gap between inner and outer tubes the convective heat transfer coefficient decreases. With rise in tube diametre the convective heat transfer coefficient also rises.

- Jayakumar et al(2010)[9] researched on variation of local Nusselt number across the length and across the circumference of the helically coiled heat exchanger. They varied parametres like pitch circle diametre, tubular pitch, tube diametre, etc and their effects on heat transfer rate. They concluded that convective heat transfer coefficient and local Nusselt number vary non-uniformly along lenth of helically coiled heat exchanger. When tube diametre is very low, mixing of fluid is very less. With rise in coil diametre the heat transfer coeffient at outer interface also increases. The pitch circle diametre increase leads to increase in secondary flow due to centrifugal force of fluid inside the tube.

- Naphon(2011)[15] studied heat transfer characteristics in a helically coiled tube-in-tube heat exchanger. He used the k-epsilon(2 eqn) turbulence model to simulate the flow and study the heat transfer characteristics of the flow. He discovered that the Nusselt number and pressure drop are nearly 1.5 times that for a straight tube-in-tube heat exchanger.

- Sunnpawar et al(2014)[17] carried out study on isothermal steady state and non-isothermal unsteady state condition in a helically coiled heat exchanger. They defined a non-dimensional number 'M' and formulated a relation between Nu, M, Pr and D/d ratio. They carried out the study for both laminar as well as turbulent flow conditions.

- Lu et al(2014)[14] studied the shell side thermal hydraulic performances of helically coiled heat exchangers for varying boundary conditions.

- Rennie et al(2006)[18] analysed a tube-in-tube helical heat exchanger. Research was done for laminar flow case. Mass flow rate and pipe sizes were varied and heat transfer coefficient variation was noted. Then relation between Nu and Dean Number was proposed.

- Yan Li et al(2010)[13] studied on high pressure shell and tube heat exchanger for Syngas cooling in an IGCC. They worked on the pressure drop and temperature change along the periphery of the heat exchanger. They concluded that more the operating pressure greater will be the heat transfer rate. The location of baffles inside the heat exchanger also influence the heat transfer characteristics of the flow. They concluded that by shortening the baffles, decreasing the number of baffles and increasing the gap between the baffles, the resistance to flow is reduced.

- Lee et al(2010)[12] studied the heat transfer characteristics of a multi-coil heat exchanger. For different coil design specifications, flow characteristics for air were studied. They studied the effects of variation of included angles in between the coils. They concluded that along with heat transfer surface area, other various factors like mass flow rate of fluid, decrease in stagnant regions of flow and uniform distribution of flow in the heat exchanger lead to increase in heat transfer rate for the helically coiled multi coil condenser.

- Huminic et al(2011)[4] studied heat transfer coefficient in tube-in-tube helically coiled heat exchanger. Nano fluids were considered for the analysis under laminar flow conditions. The nano particles implemented were CuO and Titanium Dioxide. It was found that the percentage of nanoparticles in nano fluid affects the heat transfer characteristics of the flow. Dean number also influences the heat transfer coefficients. Heat transfer coefficients improve with addition of nano particles in fluids over normal fluids. It also increases with rise in mass flow rate of fluid. With rise in Dean Number convective heat transfer coefficient can be improved.

- Ferng et al(2012)[2] studied helical coil heat exchanger. He worked to find the effect of Dean number and pitch size of the tube on the thermal and hydraulic behaviour of flow in a helical coiled heat exchanger.

- Jahanmir et al(2012)[5] worked on shell and tube heat exchanger with single twisted tube bundle in five different twist angles. They found out that for same mass flow rate the convective heat transfer coefficient for the case of twisted bundle type shell in tube heat exchanger is lower than that for shell in tube heat exchanger with segmental baffles. Also the pressure drop for shell in tube heat exchanger with twisted bundles is very less than the shell in tube heat exchanger with segmental baffles. They also found that the reduction in pressure drop is more rapid in case of heat exchanger with twisted bundles than heat exchanger with single segmental baffle. The convective heat transfer coefficient for a particular pressure drop was found at angles of 55º to 65º.

- Jamshidi et al(2012)[6] studied the methods to optimise the design of nano fluids in helically coiled tubes. They used water with aluminium oxide as the nano-particle. Laminar flow and constant wall temperature conditions were maintained for the study. Taguchi method was used to optimise the geometry of the helically coiled heat exchanger device. It was noted that use of nano-fluids improved the thermal-hydraulic performance of the heat exchanger.

- Yang San et al(2011)[22] did numerical investigation of the heat transfer characteristics of helically coiled heat exchanger. The cross-section of the heat exchanger was made rectangular with dual cover plates. They discovered that with increase in in-between spacing of the channels, friction factor rises. With rise in Reynold's number, the friction factor drops. With increase in Reynold's number and in-between spacing of channels, the Nusselt number rises.

- Zachar(2012)[23]studied the natural convection on the exterior sides of helical coil heat exchangers. They concluded that the inner fluid mass flow rate influence the external heat transfer coefficient.

- Aly et al(2014)[1] studied the heat transfer coefficient and pressure drop for the flow of nano-fluid in a helical tube-in-tube heat exchanger with turbulent flow conditions. CFD was utilised for the numerical analysis of the flow. Water with aluminium dioxide nano-particles was used as the nano-fluid. They concluded that the convective heat transfer coefficient as well as the heat exchange rate rise with rise in coil diametre and percentage of nano=particles in the nano-fluid. They also concluded that the friction factor rises with rise in D/d ratio . The loss in pressure decrease can be made negligible by increasing volume concentration of the nano-particle in the nano-fluid upto 2%. They also found that nano-fluids show behaviour similar to homogenous fluids.

- Jayakumar et al(1997)[7] studied the performance of residual heat removal system for two phase natural circulation. They used a helically coiled heat exchanger for their experiments. They varied different process parametres and studied their effect on the heat transfer coefficients.

- Eiamsa-ard et al(2005)[19] studied methods for improving heat transfer rates by putting helical tapes inside straight tube heat exchangers. They found that the helical tapes produce swirl motion which produce turbulence and so Nu rises.

- Eiamsa-ard et al(2007)[20] performed experiments on heat transfer performance with addition of helical screw tape with or without core rod inserts. Also the effect on friction factor was studied.

- Ghorbani et al(2010)[3] studied the behavior of mixed convection heat transfer in a coil-in-shell heat exchanger. The parameters varied are: Re, Ra and D/d ratio. Both laminar flow as well as turbulent flow cases are studied. They concluded that the epsilon-NTU relation of the heat exchanger and an ordinary counter-flow heat exchanger are same. Also it was found that the mass flow rate ratio is greater than 1, the temperature variation obtained was of quadratic in form. The temperature variation obtained for mass flow rate ratio 1 was linear. Mass flow rate increase leads to fall in LMTD.

- Yang et al(2011) [22] predicted the heat transfer coefficient characteristics experimentally They implemented membrane helical coils and membrane serpentine tubes in their helically coiled heat exchanger. they observed that the operating pressure, composition of gas and flow pattern influence the convective heat transfer coefficient of the gases flowing through the heat exchanger with the serpentine membranes attached to it. They concluded that the heat transfer coefficient increase was because of rise of gas pressure and increase in gas flow velocity.

- Srbislav et al(2012)[21] experimentally predicted the performance of helically coiled heat exchangers. They concluded that winding angle, radial pitch and axial pitch are the most important parametres affecting heat transfer coefficient. They also obtained a correlation between Nusselt number and Reynold's number for shell side of the heat exchanger.

From the above literature reviews we find that lot of work has already been done for optimising the design parametres for optimum heat transfer rate. Also work has been done to vary the properties of working fluid to enhance heat transfer. Lot of researchers have tried to optimise heat exchange performance by inserting baffles, tapes etc.. in helically coiled heat exchangers. Also previous works prove that the performance of helically coiled heat exchangers is superior to performance of straight coiled heat exchanger.

But no work has been done based on pulsating flow in a helically coiled tube-in-tube heat exchanger.

Chapter 3

PROBLEM FORMULATION

3.1 Introduction

In literature review it was found that extensive work has been done to optimise heat transfer rate by varying inlet conditions, design parameters and fluid properties. But not much work has been done related to pulsating flow in a helically coiled tube-in-tube heat exchanger. Also not much work has been done yet related increasing heat transfer rate by adding thin wires over the inner tube of a helically tube-in-tube heat exchanger. So, in this paper I tried to find out if replacing a constant velocity flow with a pulsating velocity flow in the same model of a helically coiled tube-in-tube heat exchanger model gives better heat transfer or not. Later, I also worked to add a thin wire over the inner tube surface of the same helically coiled tube-in-tube heat exchanger and tried to analyse if addition of the wire gives better performance of the heat exchanger or not.

3.2 Problem Specification

In this paper I try to use a standard model of a helically coiled tube-in-tube heat exchanger for studying both constant velocity flow case and pulsating velocity flow case. In actual usage, the heat exchanger specifications may vary largely from the model used here, but this study will definitely give relative idea whether for any model specification of a heat exchanger pulsating velocity flow of fluid is better than constant velocity flow or not. In real life usage various models of heat exchangers are applied. Both parallel flow and counter flow heat exchangers are used depending on requirement.

Inthis project the standard model of heat exchanger that is used has the flollowing specifications:

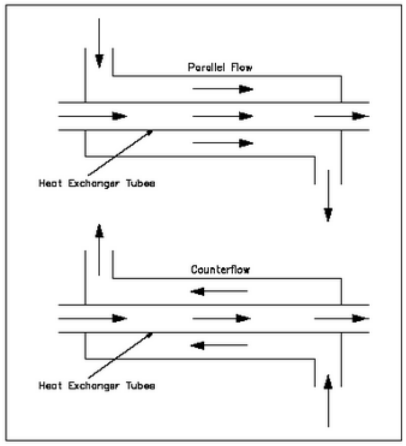


Figure 3.1: Parallel flow & Counter flow heat exchangers

GEOMETRY SPECIFICATIONS	DIMENSIONS
Inner Tube Inner Diametre	100mm
Inner Tube Outer Diametre	120mm
Outer Tube Inner Diametre	180mm
Outer Tube Outer Diametre	200mm
Height of Helix	1200mm
Coil Diametre	1600mm
Number of turns	2
Wire Diametre	10mm

Table 3.1: Geometry specifications of heat exchanger model used

FLUID INLET TYPE	TEMPERATURE(in K)
Hot fluid	363
Cold fluid	283

Table 3.2: Inlet temperature conditions

The geometry is to be created using ANSYS 15.0 workbench.

Later flow in the the model is to be analysed for both parallel flow cases and counter flow cases each. The various cases to be studied using the specified heat exchanger model are:

1. Constant velocity-parallel flow case
2. Constant velocity-counter flow case
3. Pulsating velocity-parallel flow case
4. Pulsating velocity-counter flow case
5. Pulsating velocity with wire-parallel flow case
6. Pulsating velocity with wire-counter flow case

3.3 Boundary conditions

In this project, for each case the hot fluid is flowing through the inner tube and colder fluid is flowing through the outer tube. Depending on the case, the inlet and outlet faces for the hot and cold fluids are specified.

For the constant velocity flow cases, the inlet velocity for both hot and cold fluids is to be taken as 0.5 m/sec. For pulsating velocity flow type, the inlet velocity for both hoth hot and cold fluids is to be varied with time as v=0.5*sin(4*pi*t)

3.4 Materials used

The material used for the fluid parts is taken as liquid water.

PROPERTIES	VALUES
Density	998.2 kg/m^3
Viscosity	0.001003 kg/m-sec
Specific heat capacity	4180 J/kg-K
Thermal conductivity	0.6 W/m-K

Table 3.3: Properties of water

The material used for solid part is copper.

PROPERTIES	VALUES
Density	8978 kg/m^3
Specific heat capacity	381 J/kg-K
Thermal conductivity	387.6 W/m-K

Table 3.4: Properties of copper

3.5 Assumptions

1. Flow through the heat exchanger is taken as a turbulent flow model
2. Water is considered as incompressible
3. Natural convective heat transfer and radiative heat transfers are ignored.

3.6 Governing Equations

- Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{3.1}$$

- Navier Stokes equations

1).x-component equation:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x \tag{3.2}$$

2).y-component equation:

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y \tag{3.3}$$

3).z-component equation:

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z \tag{3.4}$$

- Energy equation

$$\rho C_p \left(\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + S \tag{3.5}$$

These are the governing equations used in the analysis of the project.

Chapter 4

CFD MODELLING

4.1 Introduction

CFD(Computational Fluid Dynamics) uses numerical analysis to analyse physical fluid flow problems. Development of CFD softwares and super fast computers have made analysis of real life engineering problems a lot easier and help us find solution to these problems in less time with good accuracy. Earlier use of CFD technology was limited to aerodynamic analysis mostly. But development of modern CFD softwares like ANSYS has extended its application to daily life engineering problems. CFD sotwares comprise of

- Pre-processer: The pre-processer work includes creation of geometry related to the zone of study and formation of mesh in the geometry created. For creating geometry a design modeller is utilised. After formation of geometry as required, the geometry has to be meshed. meshing is a vital part of pre-processing operation. Optimum grid sizes have to be created in meshing. because finer the grid, more is the accuracy, but the time taken for simulation is more. So, an optimum grid size range has to be selected while meshing the geometry.

- Solver: It is the main part of CFD software. It uses the governing equations according to the options chosen by user and the boundary conditions applied to simulate the flow and analyse the flow as per the user's requirements.

- Post-processer: It helps the user to analyse the results obtained by the solver after solving the problem. It helps the user to obtain the contours of temperature, pressure and various other properties and also to obtain vector plots of velocity, etc.. as well as grahical plots of various parametres.

4.2 Geometry formation:

The geometry of the model of the helical tube-in-tube heat exchanger is created in ANSYS 15.0 workbench. The steps followed in creation of the geometry are as follows:

- Firstly, we open ANSYS 15.0 and select the Fluid Flow(Fluent) tab.
- Then we select the Geometry option and open the Design Modeller.
- We select the Y-Z plane and a 1200 mm line is created from origin along Z-axis for the height of the helix. The line is generated as Sketch 1.
- A new plane termed as plane 4 is done corresponding to the Y-Z plane.
- In this plane 4 new sketches are drawn named sketches 2, 3, 4 and 5 respectively.
- Sketch 2 consists circle of diametre 100mm.
- Sketch 3 consists of two concentric circles of 100mm and 120mm.
- Sketch 4 consists of two concentric circles of 120mm and 180mm.
- Sketch 5 consists of two concentric circles of 180mm and 200mm.
- These 4 sketches are generated as:

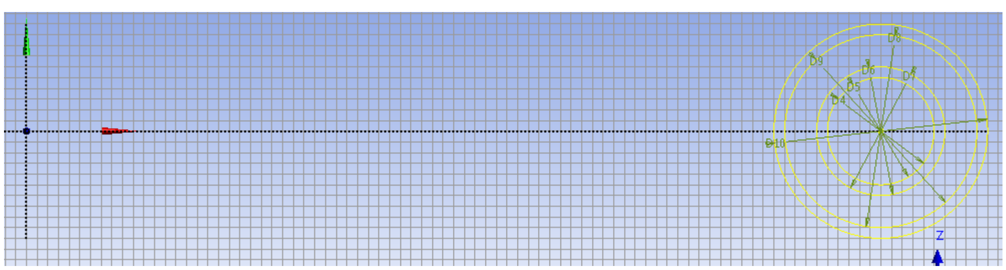


Figure 4.1: Sketches 2,3,4 and 5

- The 4 sketches are then swept using the Sweep option along sketch 1, with Add Frozen option by specifying the number of turns as 2. The geometry generated is as:

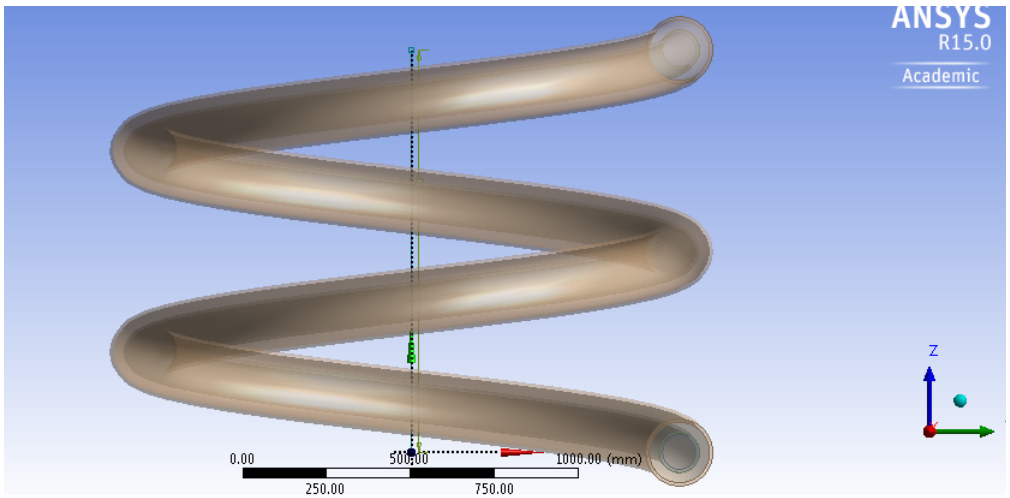


Figure 4.2: Geometry

- The various parts are then specified as solid for pipe parts and fluid for the water bodies. The various bodies are named as Inner Fluid, Inner Pipe, Outer Fluid and Outer Pipe.

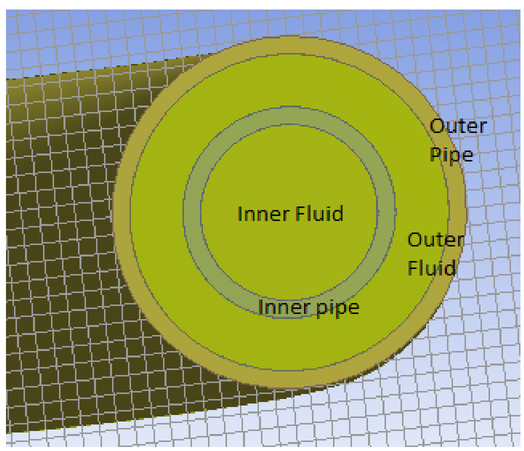


Figure 4.3: Naming of bodies obtained

- For later analysis of the heat exchanger with thin wire attached over the inner tube, a circular arc of diametre 10mm is drawn over the outer periphery of the inner tube.

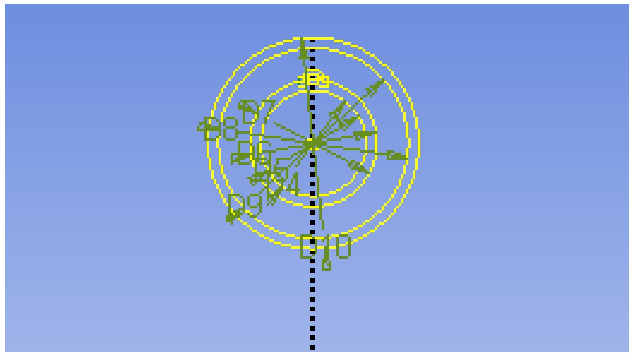


Figure 4.4: Sketch with wire

- The sketch of wire is also swept along sketch 1 with same add frozen operation with 2 turns. The geometry of the inner tube with thin wire attached over its surface is as :

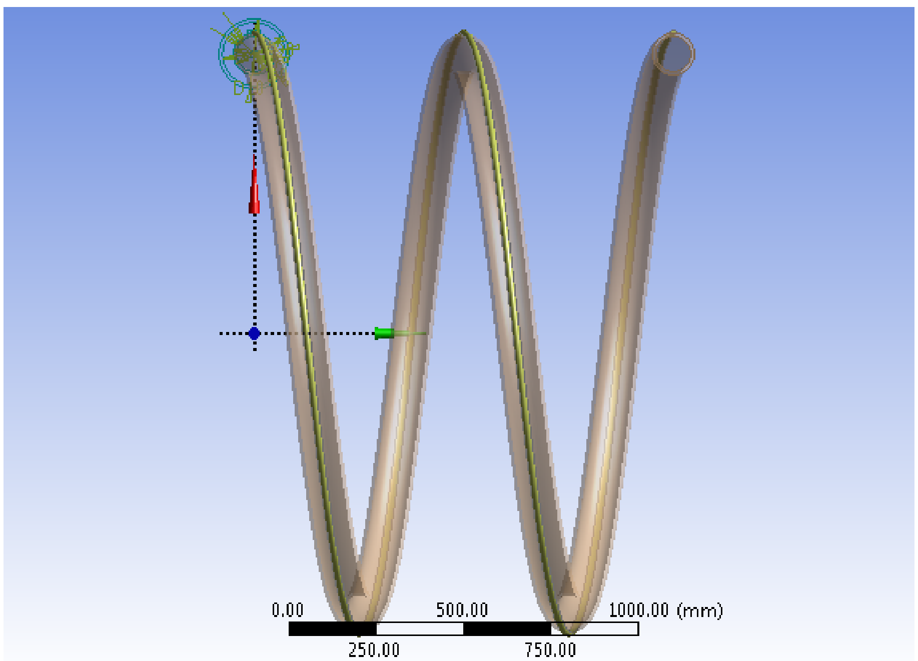


Figure 4.5: Inner tube with wire above it

4.3 Meshing

It is the most important part of the pre-processer which decides the accuracy of the final results obtained. Finer the grid size, more accurate is the result. But, the calculation will be time taking also. So optimal grid size range should be chosen. Meshing tab is opened after saving the geometry formed. Relevance centre is set to 'Fine' and smoothing is set to 'High'. Mesh is generated as per requirement. The mesh obtained here is:

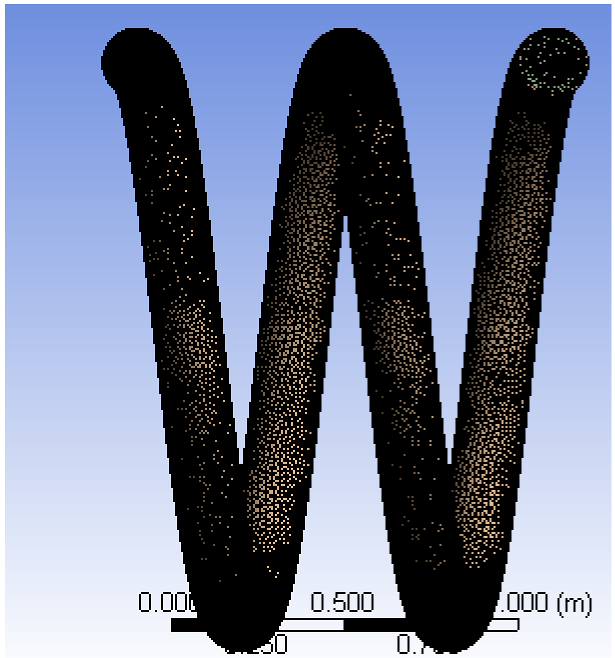


Figure 4.6: Mesh

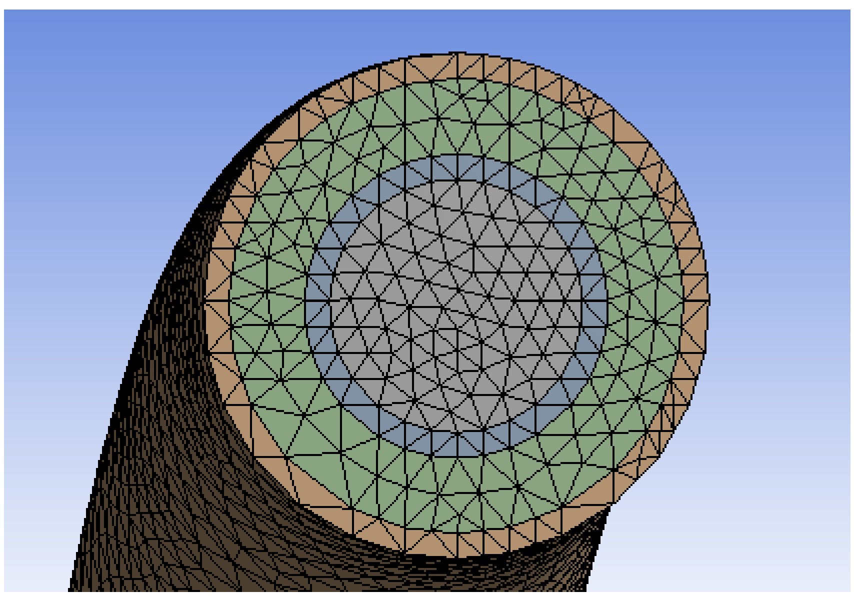


Figure 4.7: Meshing of faces

The aspect ratio obtained is 7.2 and minimum orthogonal quality is 0.4.

The mesh obtained is now saved and the the various interfaces are named using named face selection.

The various interfaces named according the case to be studied are:

1. Hot fluid-Inner pipe interface

2. Cold fluid-Inner pipe interface
3. Cold fluid-Outer pipe interface
4. Outer insulation
5. Hot fluid inlet
6. Cold fluid inlet
7. Hot fluid outlet
8. Cold fluid outlet

4.4 Setup

- After saving the meshed geometry, setup tab is opened. Double precision is selected.
- Under the general tab, type is selected as pressure based, velocity formulation is selected as Absolute and time is selected as transient.

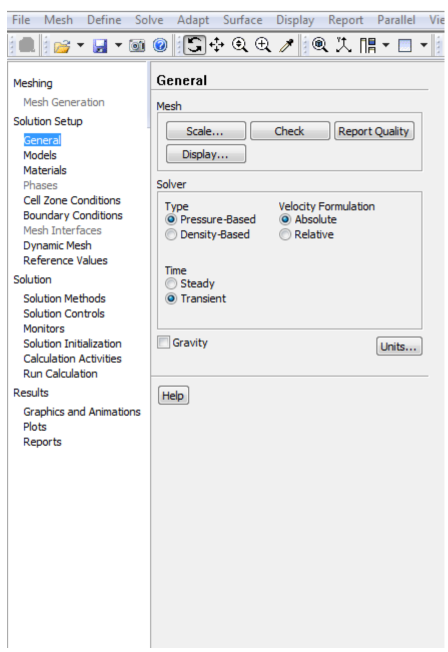


Figure 4.8: Setup General tab

- Under the Models tab, Energy is set on and viscosity is set to K-epsilon(2 eqns).

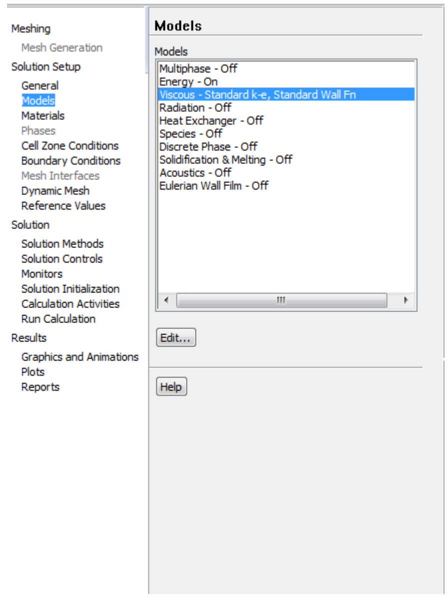


Figure 4.9: Setup Models tab

- Under the materials tab, fluid is changed to liquid water and solid is changed to copper.

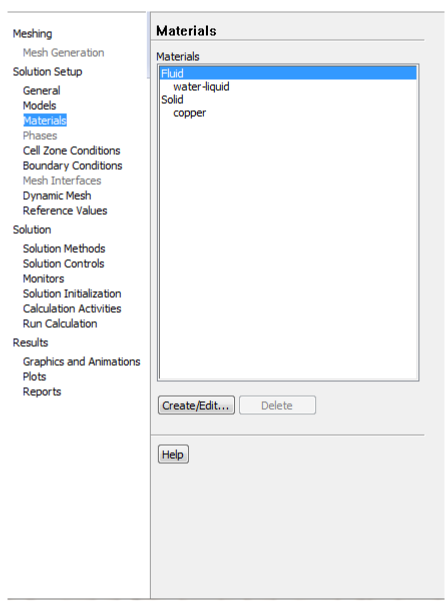


Figure 4.10: Setup Materials tab

- Under the Boundary Conditions tab, the boundary conditions are specified for each face.

- For the pulsating flow case, the required udf is interpreted.

- The hot inlet is specified as velocity inlet and the inlet velocity is changed to udf inlet velocity for pulsating flow case analysis and to 0.5m/sec for constant velocity flow analysis under momentum option. Under thermal option, the hot inlet temperature is specified 363 K.

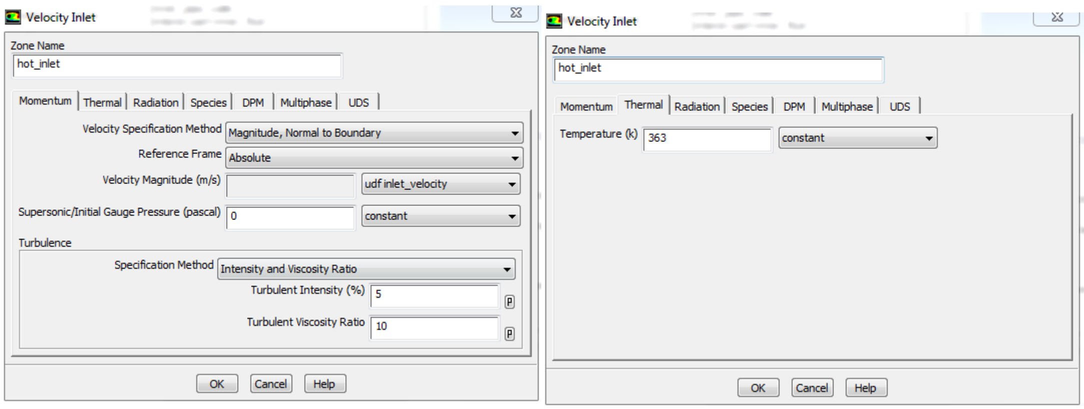


Figure 4.11: Setup boundary condition for hot inlet

- The cold inlet is specified as velocity inlet and inlet velocity is changed to udf inlet velocity for pulsating flow case analysis and to 0.5m/sec for constant velocity flow analysis under momentum option. Under thermal option, the cold inlet temperature is specified 283 K.

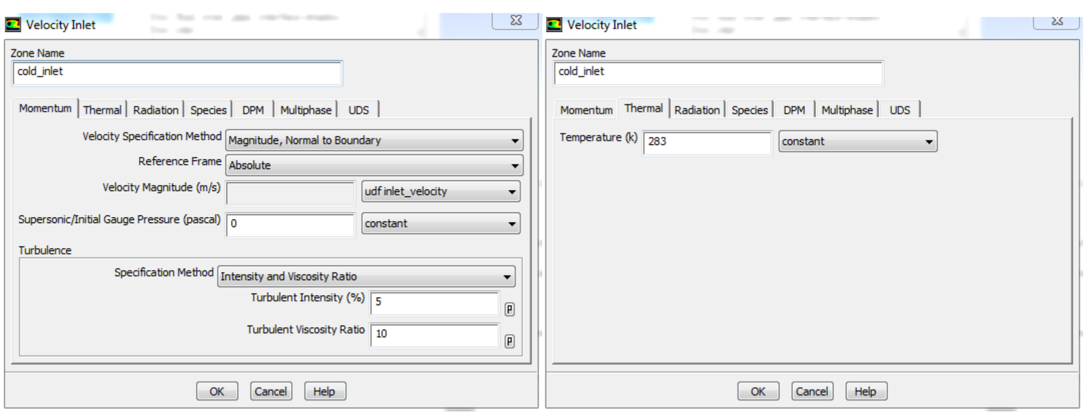


Figure 4.12: Setup boundary condition for cold inlet

- Under the boundary conditions option, for the hot fluid-inner pipe interface, cold fluid-inner pipe interface and cold fluid-outer pipe interface, the thermal condition is changed to coupled. The material is selected as copper and Shell conduction is set on by specifying wall thickness as 0.01m.

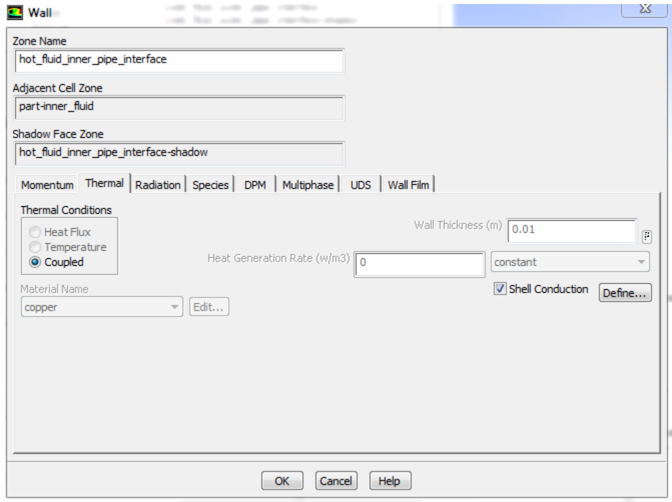


Figure 4.13: Setup boundary conditions for walls

- For the insulation faces, the thermal condition is set as Heat flux as 0 W/m^2 with Shell conduction switched off.
- Under the Solution methods tab, the scheme is set to SIMPLE, gradient to LEAST SQUARE CELL BASED, pressure to SECOND ORDER, momentum to SECOND ORDER UPWIND, turbulent kinetic energy to SECOND ORDER UPWINDand turbulence dissipation rate to SECOND ORDER UPWIND.

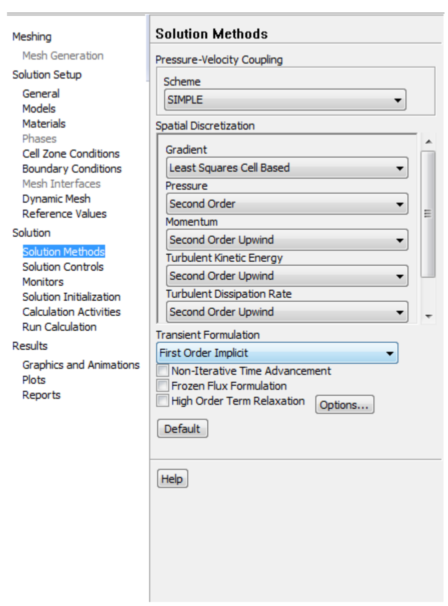


Figure 4.14: Setup Solution Methods

- Under the Solution Initialization tab, Standard initialisation is selected with 'Compute from' set to all-zones and reference frame set to Relative to cell zone.

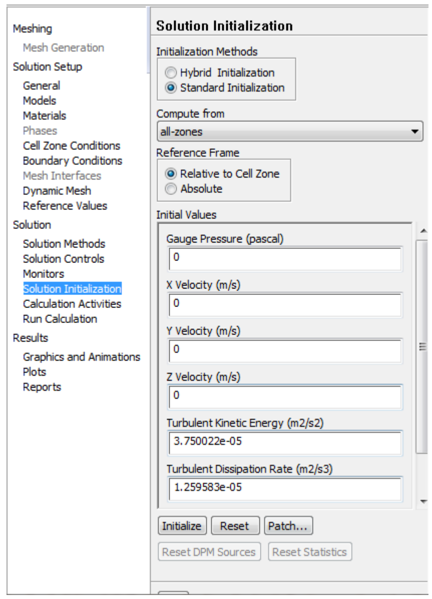


Figure 4.15: Setup Initialisation

- Then Calculation is run with Time step size set to 0.02 sec and number of time steps set to 3000. Number of iterations per time step is set to 30. Then calculation is run.
- The same procedure is repeated for the six cases to be studied and the results obtained are compared for flow time of 60 seconds.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Temperature contours obtained for hot and cold fluids for various cases after flow times of 0 sec, 30 sec and 60 sec

5.1.1 Constant velocity-parallel flow case

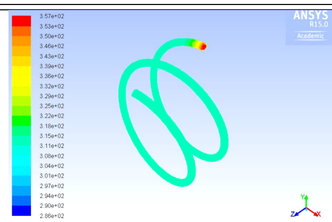
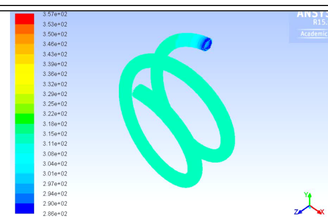
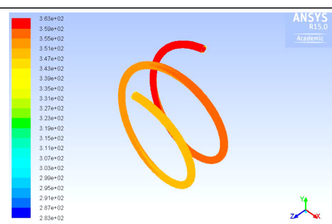
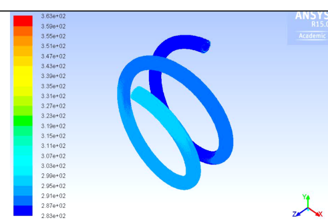
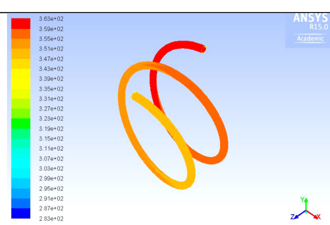
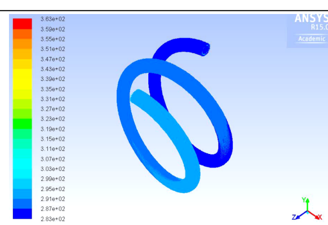
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.1: Temp contours at different time steps for constant velocity-parallel flow case

Bibliography

5.1.2 Constant velocity-counter flow case

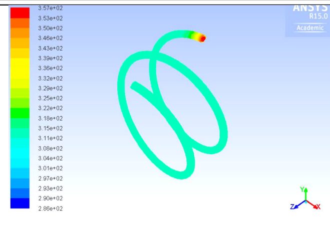
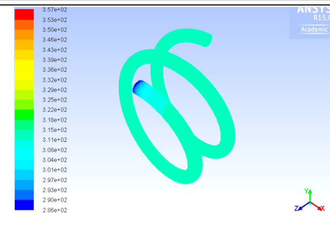
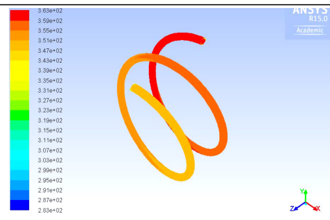
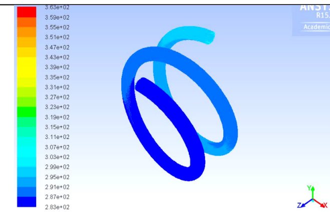
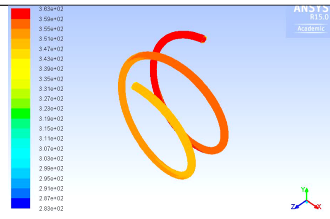
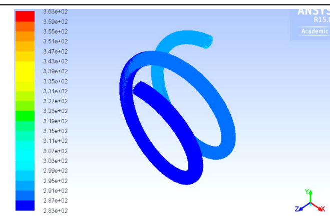
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.2: Temp contours at different time steps for constant velocity-counter flow case

5.1.3 Pulsating velocity-parallel flow case

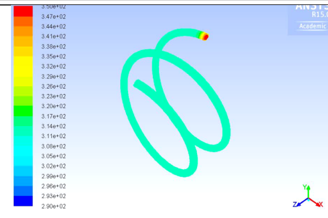
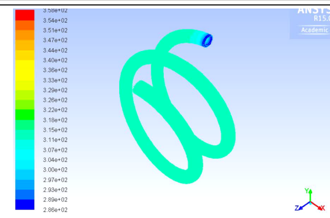
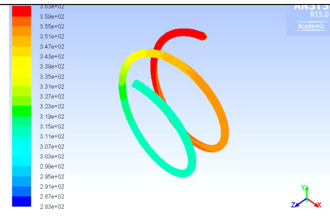
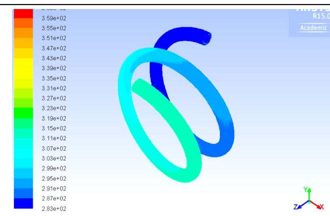
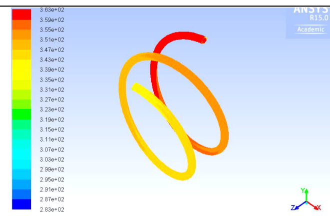
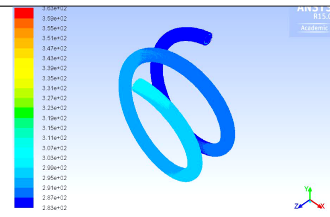
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.3: Temp contours at different time steps for pulsating velocity-parallel flow case

5.1.4 Pulsating velocity-counter flow case

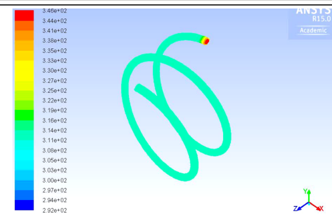
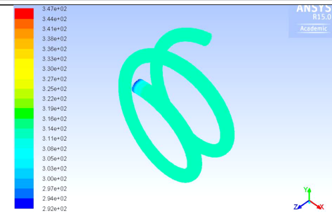
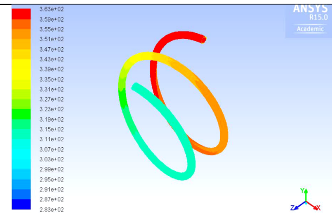
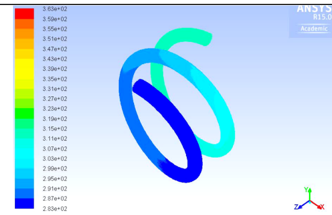
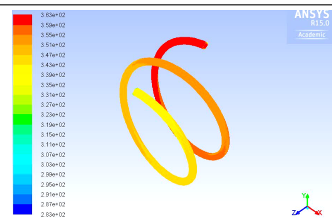
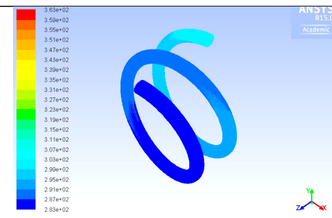
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.4: Temp contours at different time steps for pulsating velocity-counter flow case

5.1.5 Pulsating velocity-parallel flow case with wire

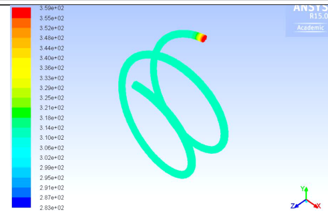
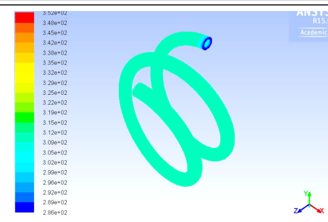
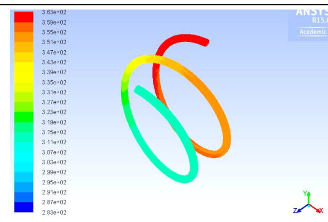
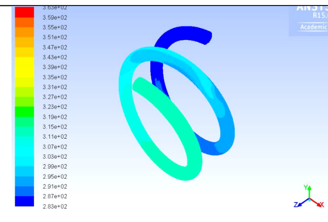
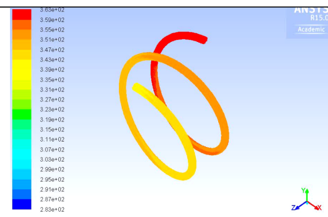
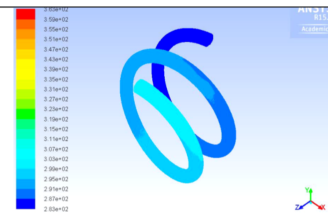
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.5: Temp contours at different time steps for pulsating velocity-parallel flow case with wire

5.1.6 Pulsating velocity-counter flow case with wire

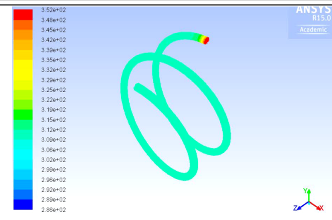
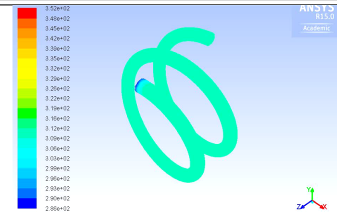
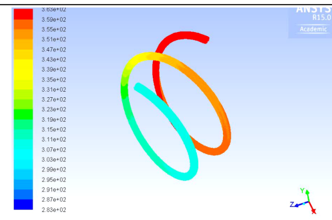
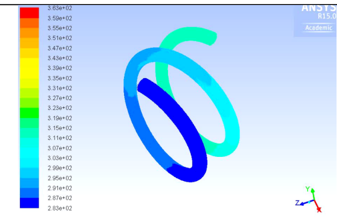
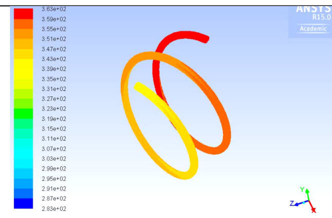
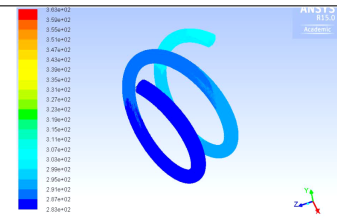
	HOT FLUID	COLD FLUID
t=0 sec		
t=30 sec		
t=60 sec		

Table 5.6: Temp contours at different time steps for pulsating velocity-counter flow case with wire

The above tables show that at the outlet of hot fluid in all the above cases have slightly orange colour for constant velocity flow, it becomes slightly yellowish for pulsating velocity case and more yellowish for pulsating velocity with wire case, for both parallel flow and counter flow cases. This indicates that for same inlet temperature, the hot fluid temperature for hot fluid outlet is greatest for constant velocity cases, comparatively lesser for pulsating velocity case and least for pulsating velocity with wire case. This shows that temperature drop for hot fluid is highest for pulsating velocity flow with wire case, lesser for pulsating velocity case and least for constant velocity flow case.

Also the hot fluid contours show that for both parallel and counter flow cases the cold fluid outlet contour colour is darkest for constant velocity flow cases and becomes lighter with pulsating velocity flow case and lightest for pulsating velocity flow with wire case. This shows that temperature rise for cold fluid is highest for pulsating velocity with wire case, slightly lesser for pulsating velocity flow case and least for constant velocity flow case.

5.2 The hot fluid temperature variations from inlet to outlet after flow time of 60 seconds:

5.2.1 Parallel flow cases

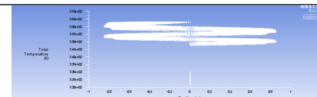
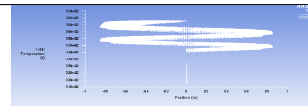
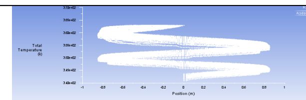
	t=60 sec	Tem drop
Constant velocity flow		15K
Pulsating velocity flow		20K
Pulsating velocity with wire		21K

Table 5.7: Hot fluid temp variation from inlet to outlet after 60 sec flow time for parallel flow cases

5.2.2 Counter flow cases

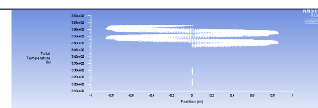
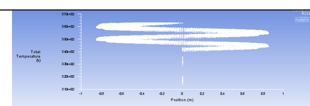
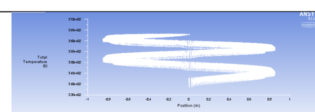
	t=60 sec	Temp drop
Constant velocity flow		15K
Pulsating velocity flow		21K
Pulsating velocity with wire		23K

Table 5.8: Hot fluid temp variation from inlet to outlet after 60 sec for counter flow cases

The above two graphs show increase in temperature drop for hot fluid for both parallel flow and counter flow cases for same heat exchanger for same flow time with change in flow type from constant velocity type to pulsating velocity type and further to pulsating velocity with wire case.

5.3 The cold fluid temperature variations from inlet to outlet after flow time of 60 seconds:

5.3.1 Parallel flow cases

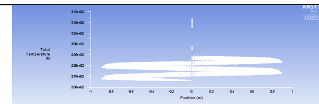
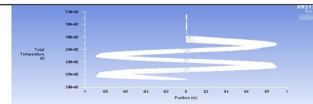
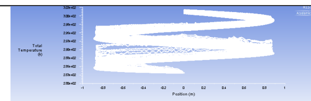
	t=60 sec	Temp rise
Constant velocity flow		10K
Pulsating velocity flow		17K
Pulsating velocity with wire		20K

Table 5.9: Cold fluid temp variation from inlet to outlet after 60 sec for parallel flow cases

5.3.2 Counter flow cases

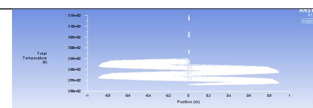
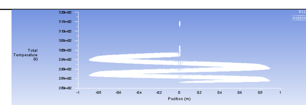
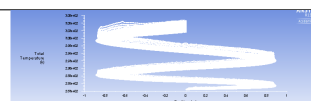
	t=60 sec	Temp rise
Constant velocity flow		10K
Pulsating velocity flow		17K
Pulsating velocity with wire		20K

Table 5.10: Cold fluid temp variation from inlet to outlet after 60 sec for counter flow cases

The above two graphs show increase in temperature rise for cold fluid for both parallel flow and counter flow cases for same heat exchanger for same flow time with change in flow type from constant velocity type to pulsating velocity type and further to pulsating velocity with wire case.

5.4 Wall temperature variations for flow time of 60 seconds:

5.4.1 Parallel flow cases

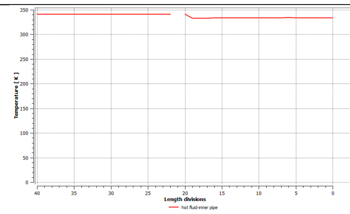
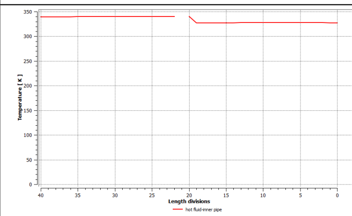
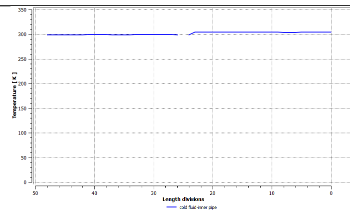
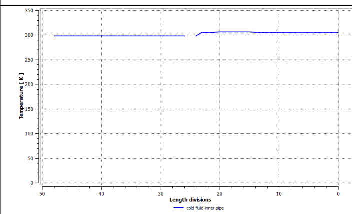
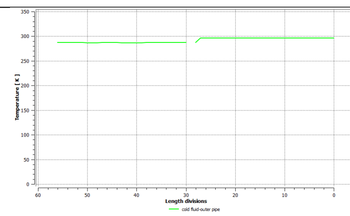
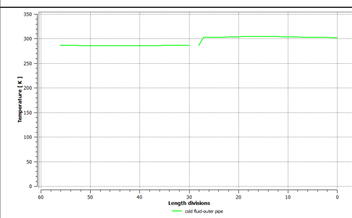
	Constant velocity flow	Pulsating velocity flow
Hot fluid-inner pipe interface		
Cold fluid-inner pipe interface		
Cold fluid-outer pipe interface		

Table 5.11: Wall temp variations for flow time of 60 sec for parallel flow cases

5.4.2 Counter flow cases

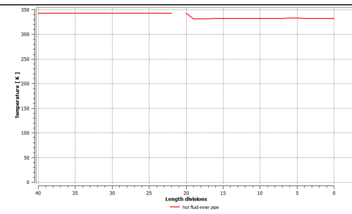
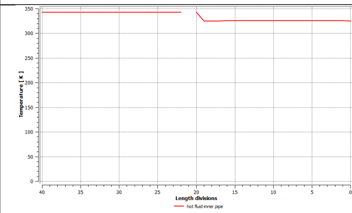
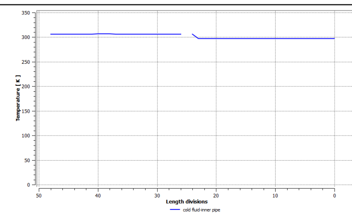
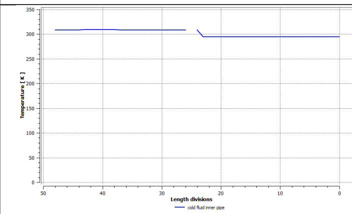
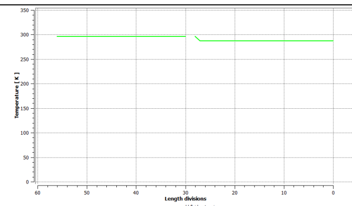
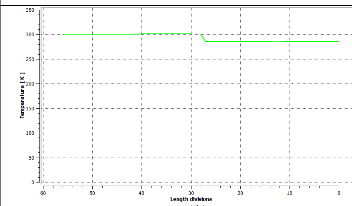
	Constant velocity flow	Pulsating velocity flow
Hot fluid-inner pipe interface		
Cold fluid-inner pipe interface		
Cold fluid-outer pipe interface		

Table 5.12: Wall temp variations for flow time of 60 sec for counter flow cases

These two tables also indicate that wall temperature drop for hot fluid-inner pipe interface as well as wall temperature rise for cold fluid-inner pipe interface and cold fluid-outer pipe interface after flow time of 60 sec in same model of heat exchanger, for both parallel flow and counter flow types, is more in case of pulsating velocity flow than constant velocity flow.

Chapter 6

CONCLUSIONS AND FUTURE SCOPE

1. Temperature drop for hot fluid and temperature rise for cold fluid increases significantly for both parallel flow and counter flow type helical tube-in-tube heat exchanger if the flow is made pulsatile rather than constant velocity type, for same flow time and same heat exchanger model. This happens due to more time available for the same amount of fluid to exchange heat.

2. If a wire is fixed above the inner tube, temperature drop for hot fluid and temperature rise for cold fluid shows slight increase than heat exchanger without wire. This happens due to increase in surface area of inner tube for heat exchange due to addition of wire. Further addition of more number of wires may result in further increase in temperature drop for hot fluid and temperature rise for cold fluid.

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